GEO/OC 103
Exploring the Deep…

Lab 6

Unit 5
Tsunami Hazards

In this unit, you will

- ***Analyze two major tsunami events in detail.***
- ***Discover the effects tsunamis have on communities and how communities can prepare for them.***
- ***Examine tsunami trigger events and develop criteria for issuing tsunami warnings.***

NOAA/NGDC/Sunset Newspaper

A major earthquake off the coast of Chile on May 22, 1960 produced a tsunami that affected the entire Pacific Basin. In Hilo, Hawaii — 10,000 km from the earthquake — the tsunami caused 61 deaths and $24 million in property damage. Frame buildings were either crushed or floated off their foundations, and only buildings of reinforced concrete or structural steel remained standing.

Reading 5.3

Analysis of a tsunami

Introduction

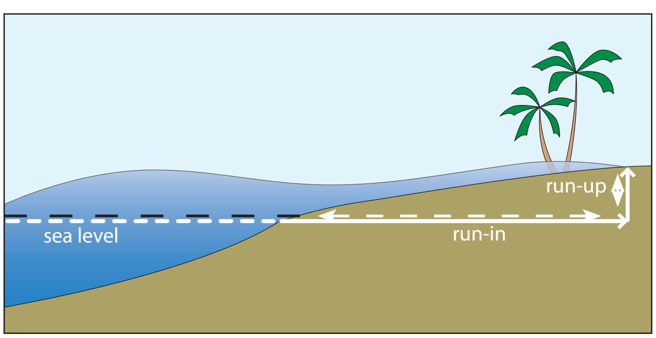
Life on Earth evolved in the protective environment of its oceans. To this day, humankind continues to take advantage of the benefits of living along the shore. Moderate temperatures, abundant food, and easy transportation are all provided courtesy of our planet's seas and oceans. Living near the ocean is not without its perils though. Perhaps the most unpredictable and terrifying of these hazards is the tsunami.

A tsunami is a series of large waves created when a disturbance displaces, or moves, an enormous volume of ocean water. The waves of a tsunami spread outward from their source at very high speed. This means that tsunamis can cross an entire ocean in a matter of hours, making them a truly global hazard for coastal communities.

Tsunamis are a special class of waves called **shallow-water waves**. The speed at which they travel is proportional to the depth of the water. In the open ocean, tsunamis move very fast but have wave heights of 1 m or less. As the water shallows near coastlines, the speed of the waves decreases while their height increases. When the waves reach the shore, they may be tens or, in extreme cases, hundreds of meters high.

Two measurements are used to describe the effect of tsunamis on the coastline.

- **Run-up** is the maximum height of the tsunami wave above normal tide level.
- **Run-in** is a measure of how far inland the wave reaches beyond the normal shoreline.



Tsunami magnitude scale

Tsunami researchers have developed a scale, based on the run-up height, for describing the intensity of a tsunami.

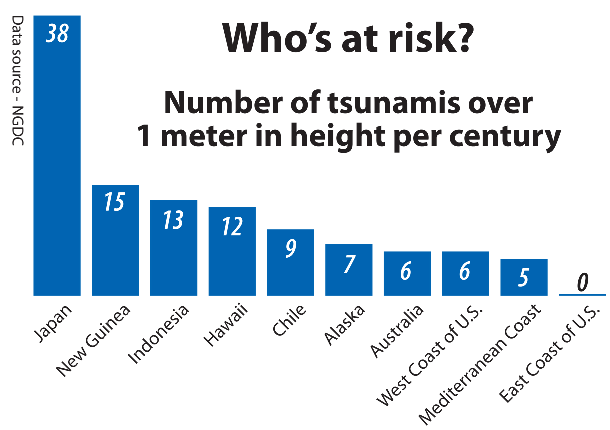
Intensity	Run-up height *m*	Description	Frequency in Pacific Ocean
4	16	Disastrous. Near complete destruction of man-made structures.	1 in 10 years
3	8	Very large. General flooding, heavy damage to shoreline structures.	1 in 3 years
2	4	Large. Flooding of shore, light damage to structures.	1 per year
1	2	Moderate. Flooding of gently sloping coasts, slight damage.	1 per 8 months

Tsunami magnitude (similar to earthquake intensity) is a measure of the local size of a tsunami.

Where tsunamis occur

In the Pacific Ocean, where the majority of tsunamis occur, the historical record shows extensive loss of life and property. Japan, in particular, has repeatedly seen entire towns and cities wiped out by tsunamis, most recently in 1993.

Most coastal communities have some degree of tsunami risk, but the chart shows that tsunamis are far more common in Pacific coastal areas than on the U.S. East Coast. This is because earthquakes and volcanoes, the features that most commonly cause tsunamis, occur more often in the Pacific Basin than in the Atlantic Basin.



Tsunamis of all sizes

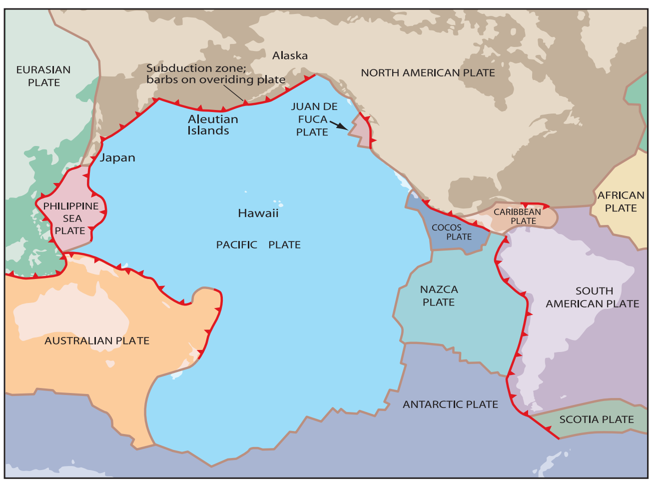
Tsunamis occur at various scales, depending on the magnitude of the event that triggers them, the location, and the surrounding topography.

- **Local tsunamis** affect an area within 200 km of their source.
- **Regional tsunamis** affect an area within about 1000 km of their source.
- **Teletsunamis** travel great distances (over 1000 km), often across entire oceans.

What causes tsunamis?

There are four types of events capable of producing tsunamis: earthquakes, volcanoes, landslides, and asteroid impacts.

Earthquakes — Normally, only large earthquakes in or near ocean basins produce tsunamis. Of these, only the strongest — magnitude 8 and higher — create teletsunamis. However, smaller earthquakes sometimes indirectly cause tsunamis by triggering landslides.



USGS

This map explains the prevalence of tsunamis in the Pacific Ocean. The red lines are subduction zones, where one tectonic plate is plunging beneath another. Earthquakes and volcanoes, two common triggers for tsunami events, are typical features of subduction zones.

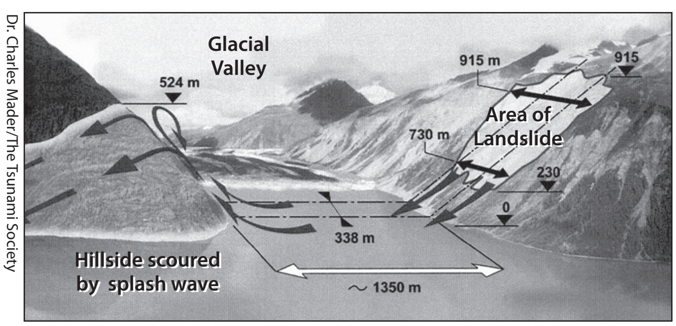
Volcanoes — Some of the most devastating tsunamis in recorded history occurred during the 1883 eruption of the volcano Krakatoa. Tsunamis with 40-m run-ups destroyed 165 coastal villages on the Indonesian islands of Java and Sumatra, killing over 36,000 people. The tsunami formed when the volcano either collapsed into its magma chamber or exploded, creating a 5- by 9-km crater. Seawater quickly filled the void, then sloshed outward as an enormous and deadly tsunami.

Landsat 7/USGS

Lyn Topinka, USGS/CVO

Krakatoa (Krakatau) sits in the Sunda Strait, a major shipping lane between the Indian Ocean and the Java Sea.

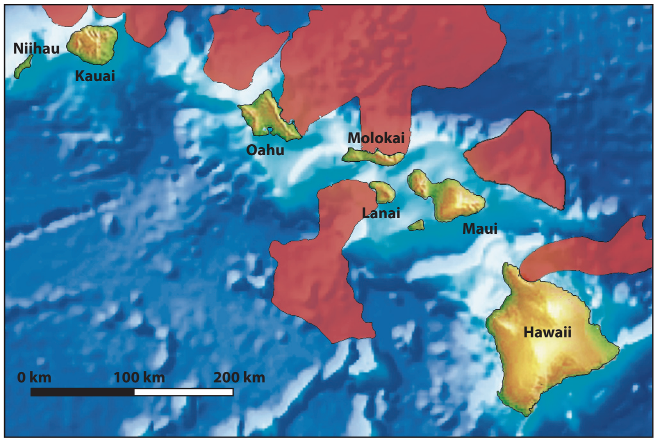
Landslides — The movement of rocks and soil can displace large volumes of water, creating a tsunami. These landslides can develop on land and fall into the water or take place completely underwater. One of the highest tsunamis in modern history occurred in Lituya Bay, Alaska when a magnitude 8.3 earthquake triggered a landslide that fell into the nearly enclosed bay. The slide created a tsunami splash wave that washed 524 m (1720 ft) over a ridge on the opposite side of the bay.



Dr. Charles Mader/The Tsunami Society

Diagram of the July 9, 1958 Lituya Bay landslide that produced a 524-m (1720-ft) local tsunami, the highest in historical times.

Scientists are also investigating submarine landslides for their tsunami-causing potential. Far more massive than terrestrial landslides, underwater landslides off the Hawaiian Islands have sent thousands of cubic kilometers of material sliding almost 200 km from their source.



Locations of major Hawaiian submarine landslides. Similar landslides may threaten the northwestern and eastern U.S. coasts with tsunamis.

The resulting tsunamis would have been enormous. There is speculation today about the origin of coral boulders 200 m above sea level on the Hawaiian Island of Molokai. Were they tossed there by a massive tsunami, or deposited by normal processes when the sea level was significantly higher?

Asteroid [and comet] impacts—The rarest yet most catastrophic cause of tsunamis is an asteroid [or comet] impact in one of Earth's oceans. Scientists estimate that a 1-km diameter asteroid striking the middle of an ocean would produce a tsunami with run-ups ranging from 6 to 50 m.

The asteroid that hit near Mexico's Yucatán Peninsula 65 million years ago, contributing to the extinction of the dinosaurs, was about 10 km in diameter. Evidence suggests that the impact generated a tsunami 100 to 250 m high that washed hundreds of kilometers inland.

Record of a tsunami event

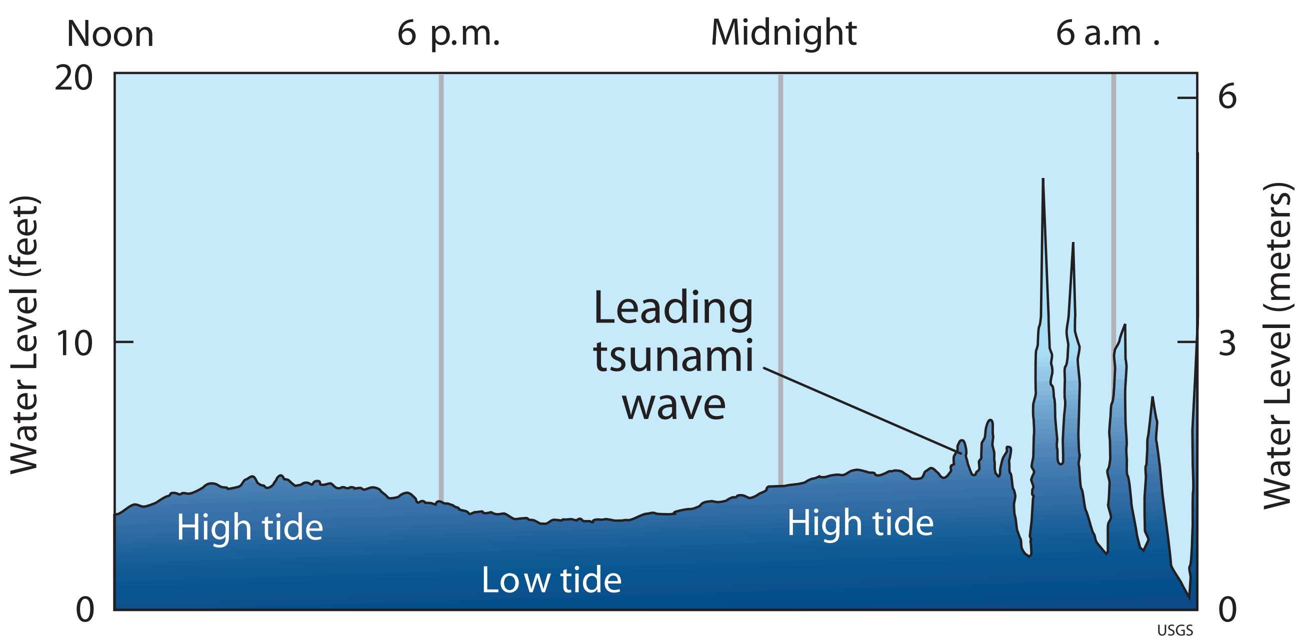
A tsunami is not a single wave, but a series of wave build-ups and retreats. The waves may be spaced minutes or hours apart. People often believe that the tsunami danger is over after the first wave has passed and are then killed when they return to coastal areas to clean up after the event.

To complicate matters, tsunamis reflect off coastlines and may pass a given location several times and from different directions. The highest run-up can occur several hours after the arrival of the first wave. Tides are another key factor, as run-up is more severe when it occurs at high tide than at low tide. All of these features of a tsunami event can be seen in the tide gauge record from the 1960 Chilean tsunami shown below.

Tsunami effects

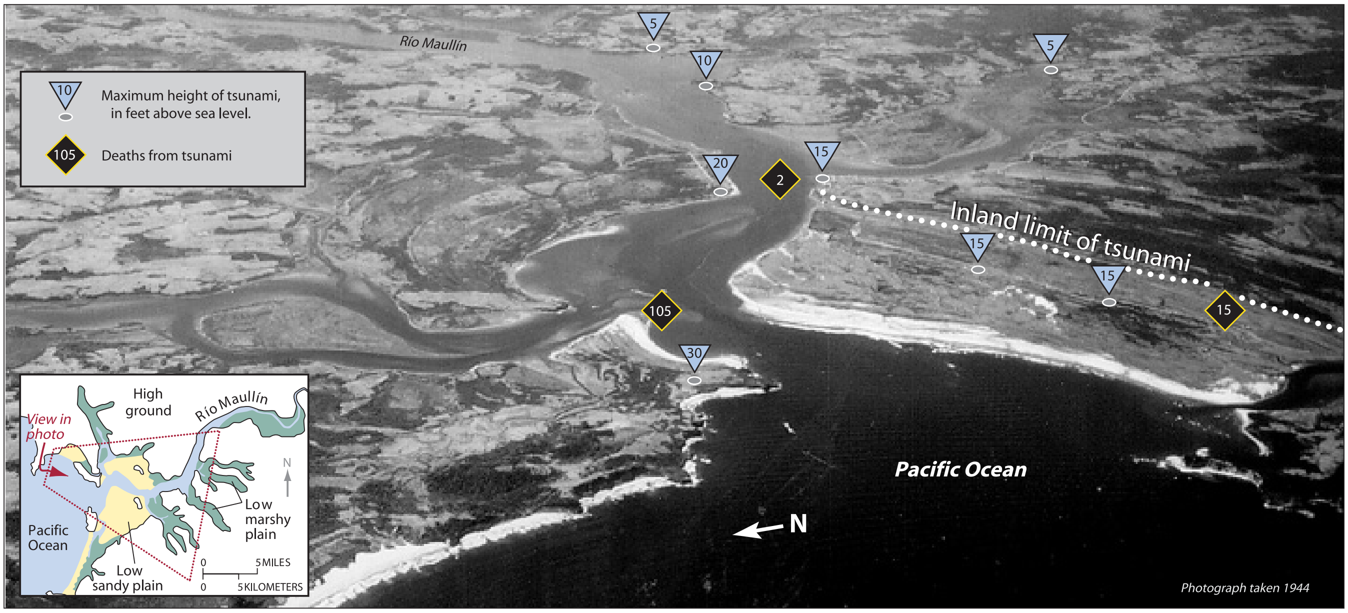
Direct Impact—Most of a tsunami's initial damage comes from the direct impact of waves on structures and harbor facilities, and from wave run-up on coastal buildings.

To get a better idea of the damage a large tsunami can do, consider that a cubic meter of pure (i.e., fresh) water has a mass of 1000 kg (2200 lb). Therefore, a 15-meter-



The May 23-24, 1960 tide gauge record for Onagawa, Japan shows a series of eight tsunamis over a 5-hour period. The first waves are not the highest. Note the deep trough preceding the first large tsunami.

USGS



Markings on this 1944 photograph of the area surrounding the mouth of Río Maullín on the Chilean coast show the extent of run-in from the 1960 tsunami. The triangle symbols are labeled with the maximum run-up, in feet, and the diamond symbols indicate where fatalities occurred.

high tsunami with a wavelength of 300 m would hit a 30-m length of seawall with a 135-million-kg (298-million-lb) wedge of water — enough to do incredible damage. Debris caught in the backwash of the leading wave makes the secondary waves even more destructive as they come ashore.

Flooding—In addition to the destructive force of the tsunamis, flooding can kill people, damage property, and spread pollution over a large area.

As shown in the photograph above, run-in from the 1960 Chilean tsunami extended about 3.2 km (2 mi) inland over flat coastal areas and penetrated almost 8 km (5 mi) up the river channels. Run-in is influenced by many factors including the run-up height, orientation relative to the coast, tidal conditions, local topography, and vegetation.

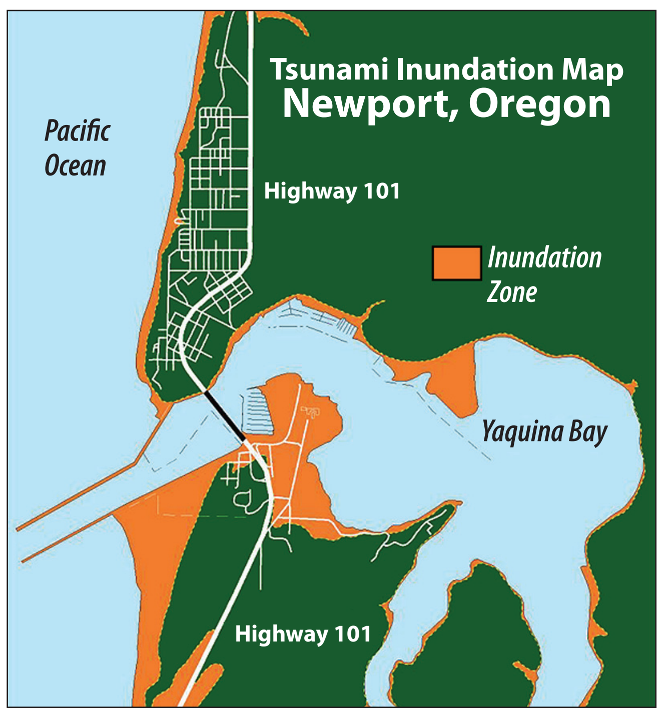
Preparing for tsunamis

Although we cannot prevent natural disasters from occurring, we can reduce their damaging effects through effective planning. Scientists and planners are working to improve our ability to detect tsunamis and issue accurate and timely warnings, to respond appropriately when they occur, and to avoid hazardous situations wherever possible.

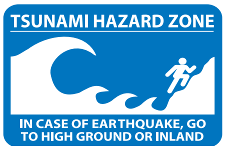
Planning ahead

Using historical and geological records, planners can predict where and how often tsunami trigger events are likely to occur. Simulating these events using mathematical models allows them to "see" the effects of tsunamis before they occur and to take corrective measures. Many coastal communities are developing tsunami preparedness plans using inundation models like the one shown below. Public education programs are a big part of these plans. For example, some communities

Oregon Department of Geology/NOAA/PMEL



Emergency managers use mathematical modeling to create tsunami inundation maps such as this. Areas prone to flooding are shown in orange, and roads and highways usable as evacuation routes are in white.

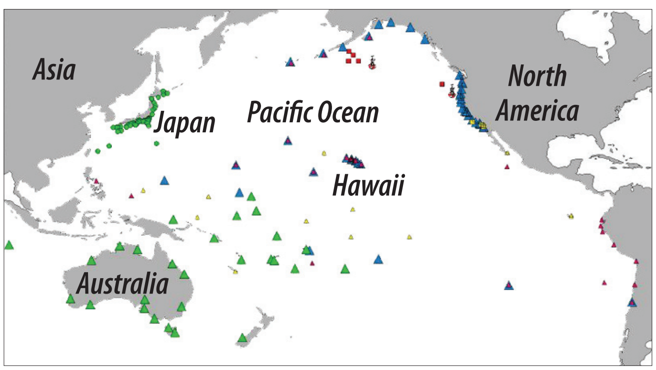


now use special signs to alert the public to tsunami hazard zones and evacuation routes.

When high-risk areas are identified before they are developed, appropriate zoning laws ensure that residential developments and large construction projects such as power stations are restricted to higher ground. In areas that have already been developed, retaining walls can be built to provide a higher level of protection. Following the 1993 tsunami, Japan's Okushiri Island built a 15-m reinforced concrete wall to protect vulnerable areas.

Monitoring and warning

Today, Pacific Rim countries use a combination of technology and international cooperation to detect tsunamis. The center of operations for this system is the Pacific Tsunami Warning Center located in Ewa Beach, Hawaii. The Center's objectives are to detect and pinpoint major earthquakes in the Pacific region, determine whether they have generated a tsunami, and provide timely warnings to people living in the Pacific region.

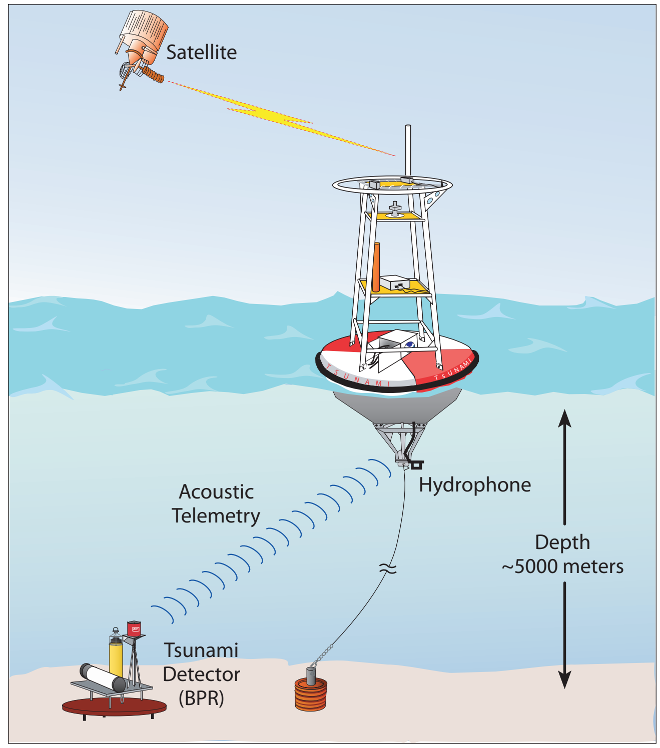


NOAA/PMEL

The Pacific tsunami detection system uses 24 seismic stations, 53 tide stations, 52 dissemination points, and 6 DART systems scattered throughout the Pacific Basin.

Deep-ocean tsunamis are difficult to detect. They average less than half a meter high, have wavelengths of hundreds of kilometers, and move at hundreds of kilometers per hour. In 1995, the Pacific Marine Environment Lab (PMEL) developed a system called DART, short for Deep-ocean Assessment and Reporting of Tsunamis. This system uses sensitive detectors to measure water pressure changes from passing tsunamis. It is capable of detecting deep-ocean tsunamis with amplitudes as small as 1 cm.

Large tsunamis are rare, and developing an accurate warning system is a challenging goal. Historically, nearly 75 percent of tsunami warnings have been false alarms. For this reason, people are often hesitant to evacuate their homes and businesses, and their response to warnings in general is poor. Emergency managers in tsunami-prone areas must work constantly to increase public awareness and acceptance of the risks of tsunamis and the emergency plans that are in place.



NOAA/PMEL

Diagram of a DART station. Placed on the seafloor, a Bottom Pressure Recorder (BPR) transmits pressure information to a surface buoy. The buoy then sends the data to the warning center through a satellite link.

Surviving a tsunami

By interviewing tsunami survivors, planners have put together these survival tips:

- **Heed natural warnings.** An earthquake is a warning that a tsunami may be coming, as is a rapid fall or rise of sea level.
- **Heed official warnings.** Play it safe, even if there have been false alarms in the past or you think the danger has passed.
- **Expect many waves.** The next wave may be bigger, and the tsunami may last for hours.
- **Head for high ground and stay there.** Move uphill or inland, away from the coast.
- **Abandon your belongings.** Save your life, not your possessions.
- **Don't count on the roads.** When fleeing a tsunami, roads may be jammed, blocked, or damaged.

- **Go to an upper floor or roof of a building.** If you are trapped and unable to reach high ground, go to an upper story of a sturdy building or get on its roof.
- **Climb a tree.** As a last resort, if you're trapped on low ground, climb a strong tree.
- **Climb onto something that floats.** If you are swept up by a tsunami, look for something to use as a raft.
- **Expect company.** Be prepared to shelter your neighbors.

Excerpted from U.S. Geological Survey Circular 1187.

Questions

1. What country is most at risk from tsunamis? Why is this?

2. Why doesn't the East Coast of the U.S. experience tsunamis more often? Are tsunamis possible there?

3. Over geological time, what has caused the most destructive tsunamis in the Hawaiian Islands?

4. How often do devastating tsunamis with run-ups of 15 m or more occur in the Pacific Basin?

5. Why is the first wave of a tsunami often not the most dangerous?

6. Why are tsunamis difficult to detect in the open ocean?

7. How can a community prepare for a tsunami?

8. When is it safe to return to coastal areas after a tsunami?

Investigation 5.4

Tsunami warning

The 1964 Alaska tsunami

💻 Launch ArcMap, and locate and open the **etde_unit_5.mxd** file.

If you encounter unfamiliar GIS terminology or are unable to perform a task, refer to the Quick Reference Sheet in the introduction to this module.

💻 In the Table of Contents, right-click the **1964 Alaska Tsunami** data frame and choose Activate.

💻 Expand the **1964 Alaska Tsunami** data frame.

The 1964 Alaska earthquake was the second strongest earthquake in recorded history and the strongest to strike U.S. territory. The earthquake, shown with the red star symbol, caused extensive damage to Anchorage both through shaking and *liquefaction* (i.e., making liquid) of the soil. The earthquake also triggered a major tsunami that seriously impacted many coastal communities, causing fatalities as far away as Eureka, California.

💻 Turn on the **Plate Boundaries** layer.

Although the epicenter of the earthquake (marked by the red star on your map) was inland, the greatest motion of the seafloor took place some distance offshore, along the Aleutian Trench. An 800-km-long slab of the North American plate was thrust suddenly upward by as much as 40 m as the Pacific plate plunged beneath it.

💻 Turn on the **Tsunami Source** layer. This shows the approximate extent of the displaced seafloor.

💻 Turn on the **Run-up Locations** layer. This layer shows sites that recorded one or more run-up measurements from the tsunami.

To view an animation of the effects of the 1964 Alaska tsunami:

💻 Select the **Trigger Event** layer.

💻 Click on the trigger-event symbol (red star) using the Hyperlink tool ⚡. Be patient while the movie loads.

💻 Use the Pause button to examine the movie at various times.

This movie is different from others you have seen. Rather than show a simulated wave, this movie uses colors to show changes from average sea level. Light blues, oranges, and reds are higher than normal sea level; darker blues are lower than normal.

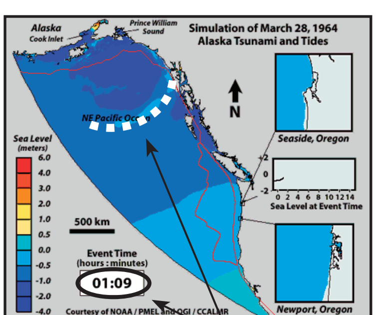
The digital clock at the bottom of the movie screen shows the number of hours and minutes that have passed since the trigger event. The movie begins 27 minutes before the earthquake and ends almost 15 hours later.

Use Pause and Play buttons to return to the frame where the clock reads 00:03. Notice the long red-orange "hill" of water that forms off the Alaska coast. As the movie advances forward in time, the hill spreads out. Follow the light blue leading edge of the tsunami southward (shown as a white dashed line in the figure at left).

Tracking the leading wave

At 1:09 after the earthquake event, the leading wave of a tsunami appears as a light blue arc traveling southward from the source. (The dashed white line does not appear in the movie.)

NOAA/PMEL

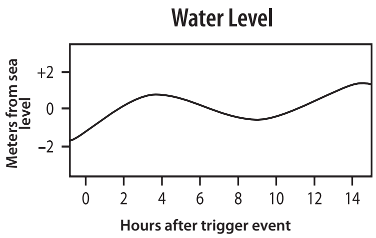


Leading wave at 1:09

Tide gauge plots

Tide gauge plots show the local water level at a gauge as it changes over time. A typical plot, in the absence of factors such as tsunamis, shows a gentle pattern of high and low tides that repeats with a period of around 13 hours.

This plot shows what the Seaside, Oregon tide gauge might have registered if the 1964 Alaska tsunami had never happened. The starting point and time scale of the plot are the same as the graph in the movie.



Tides and tsunamis

Tide gauges are devices used to record changes in sea level at coastal locations. Run the movie through several more times, each time focusing your attention on the tide gauge record at Seaside, Oregon. Normal tides would create a regular, gently changing record of the water level like the one shown at left. Watch the leading wave and the tide gauge; you should be able to see the "arrival signature" of the leading wave on the tide gauge readout.

The arrival signature is found where the gauge readout in the movie first differs from the plot in the sidebar to the left.

1. How long did it take the leading wave to reach Seaside, Oregon?

Continue the movie and watch the tide gauge. Earlier you read that tsunamis slosh around an ocean basin (like water in a bathtub). If the waves have enough energy, they can reflect off coastlines and return at a later time. When you reach the end of the movie, answer the following questions.

2. According to the tide gauge, how many secondary waves struck Seaside after the leading wave? (One wave may be very difficult to see in the plot.)

3. Was the leading wave the highest? If not, how many hours after the trigger event did the highest sea-level run-up occur? There were actually two peak waves at Seaside; record them both.

4. Based on what you've seen, is it safe to return to low-lying coastal areas immediately after the leading wave? Explain your answer.

Close the Media Viewer window when you are finished.

Tsunami trigger events

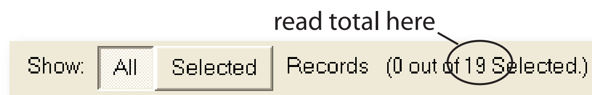
Click the QuickLoad button.

Select **Data Frames**, choose **Tsunami Hazards** from the list, and click **OK**.

Now that you have an idea what tsunamis are and how they travel, you will look at the geologic trigger events that cause them. Any event that displaces a large volume of seawater can generate a tsunami. These trigger events include volcanic eruptions, underwater and coastal landslides, earthquakes, and even (rarely, thank goodness) asteroid impacts. Each of the red star symbols in the **Tsunami Sources** layer represents an event that triggered a tsunami in the 20th century. Next, you will examine these data to find out how common each type of trigger event is.

How often do tsunamis occur?

- Select the **Tsunami Sources** layer.
- Click the Open Attribute Table button.
- Read the total number of events recorded since 1900 at the bottom of the table. (Your answer will be different than the example shown below.)



5. What is the average number of tsunami events recorded each year? (Divide the total number of events by 100 years.)

What causes most tsunamis?

- Scroll across the table to the **Event Type** field. Scroll down the table to see the different types of trigger events.

6. What is the most common type of tsunami trigger event?

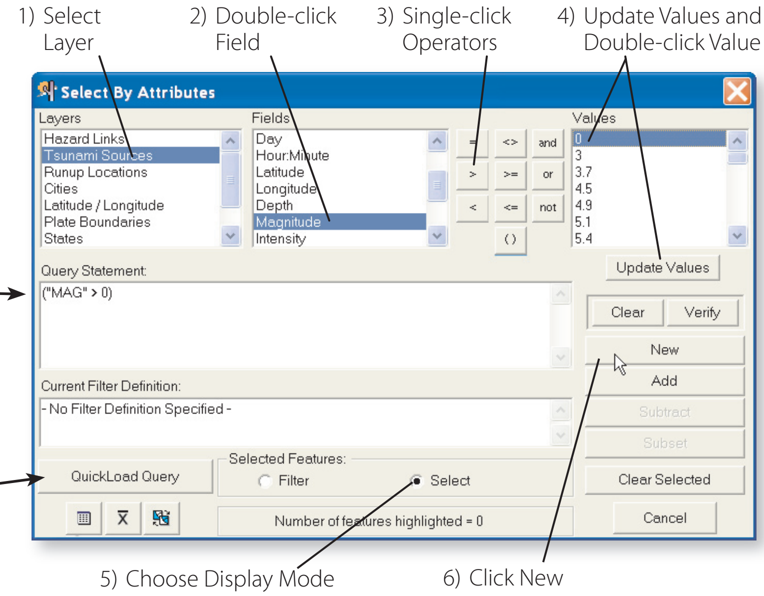
- Close the attribute table.

Tsunami warnings

Not all earthquakes produce tsunamis. It's a good idea to warn people of an approaching tsunami, but evacuations are expensive and carry their own risks (panic, looting, etc.). Is there some minimum earthquake magnitude associated with tsunamis? To find out, you will examine the **Tsunami Sources** layer for all events that have an earthquake magnitude greater than zero.

- Click the Select By Attributes button.
- To display the locations of events with magnitudes greater than zero, query the **Tsunami Sources** layer for **("Magnitude" > 0)** as shown in steps 1-6 on the following page. Your query will actually read:

("MAG" > 0)



Read query statement here as you enter it.

QuickLoad Query

- Click the QuickLoad Query button and select the **Tsunami EQ Trigger Magnitude** query.
- Click **OK**.
- Click **New**.

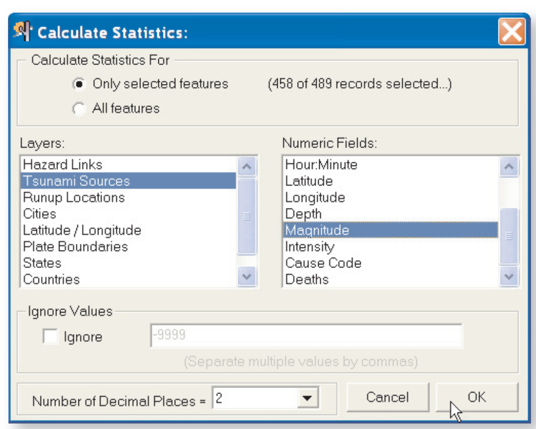
If you have difficulty entering the query statement correctly, refer to the **Quickload Query** described at left.

The tsunamis generated by earthquakes with known magnitudes are now highlighted on your map.

To find magnitude statistics for these tsunamis:

Click the Statistics button [Σ] in the Select By Attributes window.

In the Statistics window, calculate statistics for **only selected features** of the **Tsunami Sources** layer, using the **Magnitude** field.



Click **OK**. Be patient while the statistics are calculated.

7. Record the following statistics about the earthquakes that cause tsunamis.
   a. Average magnitude (**Mean**) =
   b. Highest magnitude (**Maximum**) =
   c. Lowest magnitude (**Minimum**) =

Close the Statistics and Select By Attributes windows.

Click the Clear Selected Features button .

Use these statistics to help answer the following questions.

8. Create a list of criteria that you would use to decide whether and when to issue a tsunami warning. Explain each of your criteria.
   a. What size trigger event requires a warning? How close or how far away would it have to occur?
   b. How would your local geography figure into your decision?
   c. When would you issue the warning?
   d. Which officials would you notify? How would you notify them?
   e. What would you tell them?
   f. When would you issue an "all clear" signal?

9. Since 1948, more than 75 percent of tsunami warnings have been false alarms, because it is difficult to predict the impact of a tsunami. Currently a warning is issued each time there is an earthquake of magnitude 6.7 or greater near a coastline or in the open ocean. Do you think it is better to "assume the worst" and send out too many warnings or "assume the best" and send out too few? Explain.

Quit ArcMap and do not save changes.